The first polarized Proton Collisions at the STAR experiment at RHIC

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The first run of transverse polarized protons at RHIC was recently completed which opened a new era exploring the spin structure of the proton. A first measurement of the single transverse spin asymmetry, A_N, for leading π^0 production from transverse colliding polarized protons at $\sqrt{s} = 200\,\mathrm{GeV}$, $x_F > 0.25$ and $p_T \simeq 1 - 4\,\mathrm{GeV}$ was a focus of the STAR collaboration during the first polarized proton run at RHIC. Two new subcomponents have been added to the STAR experiment to carry out such a measurement in polarized proton collisions: a forward π^0 detector system at approximately 7.8 m of the STAR interaction region to reconstruct π^0 mesons from their decay products ($\pi^0 \rightarrow \gamma\gamma$) and a beam-beam counter with large forward acceptance to provide a means of beam-related background suppression and relative luminosity measurement.

1 Introduction

The spin of elementary particles is as fundamental to their nature as their mass. The proton is a fermion of $J = 1/2$. The proton itself consists of valence quarks, gluons and quark-antiquark pairs, known as the sea. Quarks and gluons are the fundamental ingredients of QCD. Unpolarized electron-proton collider experiments (ZEUS/H1) and several lepton-nucleon fixed-target experiments have played an important role in our current understanding of hadronic matter. Similarly to the unpolarized case, several polarized fixed-target experiments have been conducted in the past to gain a deeper understanding of the spin structure of the proton. Those experimental efforts have been restricted to large values of Bjorken x. The proton spin is understood to be made up of contributions arising from the quark spin, the gluon spin and orbital angular momentum. The fundamental question in this regard is how the proton spin is distributed among those contributions. It was found in polarized lepton-nucleon experiments that only about 1/3

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of the proton spin is carried by quarks and anti-quarks, contrary to the expectation of the constituent quark model that the proton spin would be carried dominantly by its three valence quarks. A significant fraction of the proton spin must therefore be carried by gluons and orbital angular momentum. The role of the gluons to make up for the missing proton spin is currently only very poorly constrained from scaling violations in fixed target experiments. A need for a new generation of experiments to explore the spin structure of the proton is clearly apparent. The current spin physics effort at RHIC at BNL focuses on the collision of polarized protons to gain a deeper understanding of the spin structure of the proton in a new, previously unexplored territory. The first polarized proton run from December 2001 until January 2002 is the beginning of a multi-year experimental program which aims to address a variety of topics related to the spin structure of the proton such as: 1. spin structure of the proton (gluon contribution of the proton spin, flavor decomposition of the quark and anti-quark polarization and transversity distributions of the proton), 2. spin dependence of fundamental interactions, 3. spin dependence of fragmentation and 4. spin dependence of elastic polarized proton collisions. A recent review of the RHIC spin program can be found in [1].

The principle approach to study spin effects is to measure an asymmetry (A) which quantifies the normalized difference of measured yields for different initial-state spin configurations. Ultimately, any combination of beam polarization, i.e. either longitudinal (L) or transverse (T), will be possible at RHIC to access different aspects of the proton spin structure. A crucial fact to remember is that the statistical significance of double spin asymmetries varies as $P^4 \int Ldt$ whereas for single spin asymmetries it varies as $P^2 \int Ldt$. Thus, the demand on high polarization is particularly important for the measurement of double spin asymmetries. In the following, two prominent examples of asymmetry measurements in polarized proton collisions will be discussed.

The measurement of the double longitudinal spin asymmetry, A_{LL}, for photon production allows the extraction of the gluon polarization, $\Delta G/G$. A_{LL}. In LO QCD, employing factorization of the underlying hard process the asymmetry measured for $\vec{p} + \vec{p} \rightarrow \gamma + \text{jet} + X$ is represented as: $A_{LL} = \frac{\Delta G(x_g)}{G(x_g)} \cdot A_1^p(x_q) \cdot \hat{a}(g + q \rightarrow \gamma + q)$. The ratio of the polarized and unpolarized structure function, $A_1^p(x_q)$, is measured in polarized deep-inelastic scattering and $\hat{a}(g+q \rightarrow \gamma + q)$ is calculated in pQCD. Hence A_{LL} for prompt photons detected in coincidence with the away-side quark-jet allows an extraction of the gluon polarization $\Delta G(x_g)/G(x_g)$.

A focus of the first polarized proton run at the STAR experiment was the measurement of a single transverse spin asymmetry, A_N, to achieve a first polarization observable measurement at RHIC. Non-zero values for A_N have been observed at the FNAL E704 [2] experiment for $\vec{p} + p \rightarrow \pi + X$ at $\sqrt{s} = 20\,\text{GeV}$ and $0.5 < p_T < 2.0\,\text{GeV}$. Theoretical models that explain the E704 data also predict non-zero values for A_N for pion production at RHIC. Qiu and Sterman [3] attribute the measured asymmetry to a higher-twist pQCD effect. The group of Anselmino and Leader [4] perform a global analysis of semi-inclusive DIS data from HERMES [5] and E704 data. This approach involves initial ('Sivers effect') as well final ('Collins effect') state fragmentation effects to account as possible explanations for the measured asymmetries.

Besides the theoretical interest in measuring A_N, it could serve as a potential candidate to monitor the RHIC beam polarization at a particular experiment ('local polarimeter').

2 The polarized proton collider RHIC

The first collisions of polarized protons occurred in December 2001, ushering in a a new era to complement the ongoing relativistic heavy-ion program. RHIC is the first accelerator to accelerate and collide polarized protons, ultimately at high luminosity, at a center-of-mass energy of up to 500 GeV.

The key to maintain the proton polarization through acceleration despite its large anomalous magnetic momentum, is to perform a rotation of the proton spin by 180° in the horizontal plane

Figure 1: *Schematic of the STAR beam-beam counter BBC (left) and forward pion detector (FPD) (right).*

around a particular axis. This manipulation is performed by helical dipole magnets, known as 'Siberian snakes', which have been used for the first time at a proton collider. With two Siberian snakes installed in each ring, cumulative tilt effects of the proton spin are canceled, thereby eliminating the influence of depolarizing spin resonances. Besides the installation of Siberian snakes, the PHENIX and STAR experiments will be equipped with spin rotator magnets to allow for the precession from transverse to longitudinal polarization and thus to collide longitudinal polarized proton beams.

The first polarized proton run at RHIC was carried out at a center-of-mass energy of 200 GeV. Each ring was loaded with 55 bunches of alternating polarization resulting in a a bunch crossing-time of 214 ns. A transverse polarization of about 20 % was achieved at the injection energy of 24.6 GeV and was approximatley maintained when the protom beams were accelerated to 100 GeV.

3 Upgrade of the STAR detector for the first polarized proton run

The goal of the first RHIC polarized proton run at the STAR experiment was the measurement of the single-transverse spin asymmetry A_N for forward π^0 production at $x_F \simeq 0.1 - 0.6$ and $p_T \simeq 1 - 4\,\mathrm{GeV}$. A_N is extracted from :

$$A_N = \frac{1}{P} \frac{N^{\uparrow} - R \cdot N^{\downarrow}}{N^{\uparrow} + R \cdot N^{\downarrow}} \tag{1}$$

which requires three independent measurements: 1. the spin-dependent yields ($N^{\uparrow(\downarrow)}$) of forward π^0 production, 2. the relative luminosity $R = L^{\uparrow}/L^{\downarrow}$ and 3. the actual beam polarization P.

The latter is the focus of a dedicated effort at RHIC to obtain a fast (relative) polarization measurement using pC elastic scattering at very small $|t|$ values. This Coulomb Nuclear Interference polarimeter will ultimately be calibrated to pp elastic scattering for a polarized hydrogen gas-jet target.

An upgrade program at the STAR experiment was performed with the installation of a beam-beam counter (BBC) and a forward-pion detector (FPD). As well, the commissioning of the barrel electromagnetic calorimeter (BEMC) modules and trigger was undertaken. Ultimately, the BEMC will play a crucial role in measuring prompt photons and jets. In addition, a spin scaler system was commissioned to account for the beam polarization reversals every bunch crossing of 214 ns.

A layout of the BBC can be seen in Figure 1 (left). It consists of a hexagonal scintillator array structure at ± 3.5 m from the nominal interaction point. The BBC is the main device to make the relative luminosity measurement and to provide a trigger to distinguish $\vec{p}\vec{p}$ events from beam related background events by means of timing measurements.

The FPD system, shown in Figure 1 (right), consists of three lead-glass electromagnetic calorimeter modules together with a lead-scintillator calorimeter, which is a prototype module of the STAR endcap calorimeter. The latter device allows the reconstruction of π^0 mesons

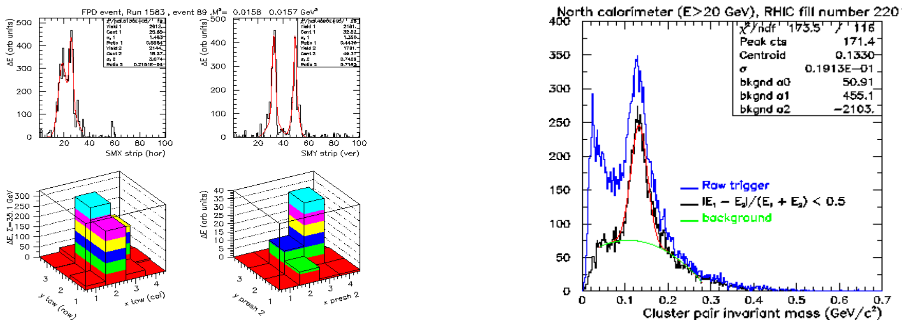

Figure 2: *FPD transverse shower profile (left) and invariant mass distribution of π^0 candidate events (right).*

from their decay products ($\pi^0 \rightarrow \gamma\gamma$) by measuring the total energy and the transverse shower profile. It consists of 12 independent towers, pre-shower detectors and a shower-maximum detector to perform a transverse shower profile measurement. This prototype module has been extensively studied using high energy electron test beams at SLAC. Its testbeam performance is well reproduced by a GEANT simulation.

The FPD transverse shower profile for a typical event of the shower maximum detector is shown in Figure 2 (left) together with the calorimeter and pre-shower detector response. The cluster separation measured in the shower maximum detector and the measured calorimeter energy serves as input to the actual π^0 mass determination. π^0 mesons of up to 60 GeV have been reconstructed. A clearly identified π^0 mass peak can be seen in Figure 2 (right). Those results are very encouraging to extract A_N from forward π^0 production and thus to study expected spin dependent effects in polarized proton collisions at RHIC.

4 Summary and outlook

The first polarized proton run at RHIC started a new era at BNL of exploring the spin structure of the proton. The main focus of the STAR experiment during the first polarized proton run of transverse polarization was the measurement of a single transverse spin asymmetry of forward π^0 production. In preparation of the first polarized proton run, an upgrade of the STAR experiment was performed with the installation of a beam-beam counter and a forward pion detector system, besides the commissioning of a spin scaler system. First results show a clear identification of forward produced π^0 mesons.

The STAR detector will undergo major upgrade programs with the installation of the endcap calorimeter which is the principal device to explore the gluon polarization of the proton and the barrel calorimeter besides a completion of the beam-beam counter. An upgrade proposal for a new forward pion detector system is currently under preparation.

An exciting time is ahead of us to explore the spin structure of the proton in a previously unexplored territory.

References

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